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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA

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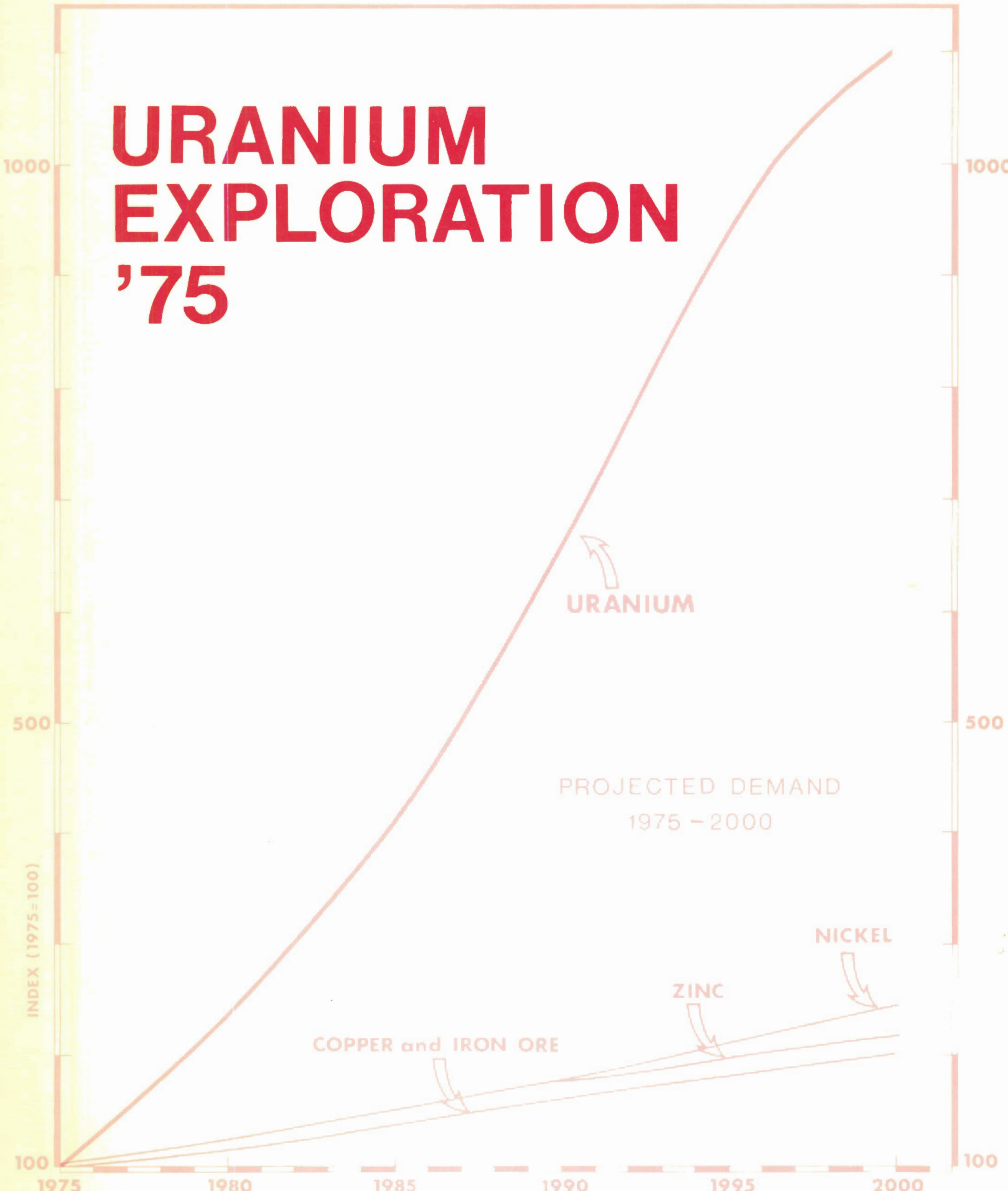
URANIUM EXPLORATION '75



1975

1. URANIUM TO 2000, AN EXPLORATION CHALLENGE

R. M. Williams

Abstract

World demand for uranium will grow at the unprecedented rate of some 15 to 20 per cent a year over the next ten to fifteen years. To meet this demand, it is estimated that the current level of world reserves of uranium must be increased by some 2. 6 million tons of U_3O_8*, over the period from 1975 to 1990. By 1990 annual gross additions to reserves will have had to triple to something in the order of 270 000 tons of* U_3O_8 *per year. The total number of deposits and the total tonnage of* U_3O_8 *that needs to be discovered and developed, however, will vary widely depending on the order in which deposits of different sizes and grades will come on stream.*

If uranium is to be discovered and developed for production at a rate sufficient to meet demand, there must be a rapid and accelerating expansion of exploration effort. However, this alone will not be enough! Exploration philosophies must be re-examined and, perhaps, modified; and a more effective and systematic use of all available exploration technology must be a prerequisite. Even more important, new methods of financing these efforts must be developed, that will satisfy the growing aspirations of governments and, at the same time, provide the needed financial incentive to industry, as well as an assurance of supply to participating consumers.

Introduction

The paper reviews the current status of the supply-demand situation for uranium, and attempts to cover the subject with the objective of illustrating the size of the uranium exploration challenge for the remainder of the century in terms of the quantity of uranium that must be discovered and the rate at which the discoveries must be developed.

Some significant factors which may be inhibiting the industry's response to the challenge to discover more uranium are also reviewed, with the objective of generating some discussion and, hopefully, some constructive ideas.

Uranium Demand

Forecasting future requirements for any commodity is a notoriously difficult exercise. In the case of uranium, however, the exercise is made marginally easier in that its future use is almost entirely related to the generation of electricity. An estimate of the future demand for electricity, in turn, is dependent on the expected growth, in consumption of total energy, on forecasts of future economic growth, and ultimately on forecasts of future population growth. Although there are uncertainties associated with all of these factors, the uncertainties are related largely to the long term. Expectations for the next ten years tend to be relatively firm.

One of the most recent forecasts of nuclear power growth is that published by the United States Atomic Energy Commission (USAEC) in early 1974. This study projected that installed world nuclear capacity will increase from some 50 000 MW in 1974 to between 2. 5 and 4. 0 million MW in the year 2000, when more than half of all electricity will be generated by nuclear power. It is pertinent to note that at the end of 1974, 350 000 MW of nuclear capacity was either operating, under construction, or ordered, virtually confirming predictions for the early 1980's. To put this in perspective, this represents forward construction commitments on the part of electrical utilities of some 150 or 200 billion dollars.

These projections of installed nuclear capacity translate into requirements for uranium as shown in Figure 1. 1. The middle range of these projections

Figure 1·1

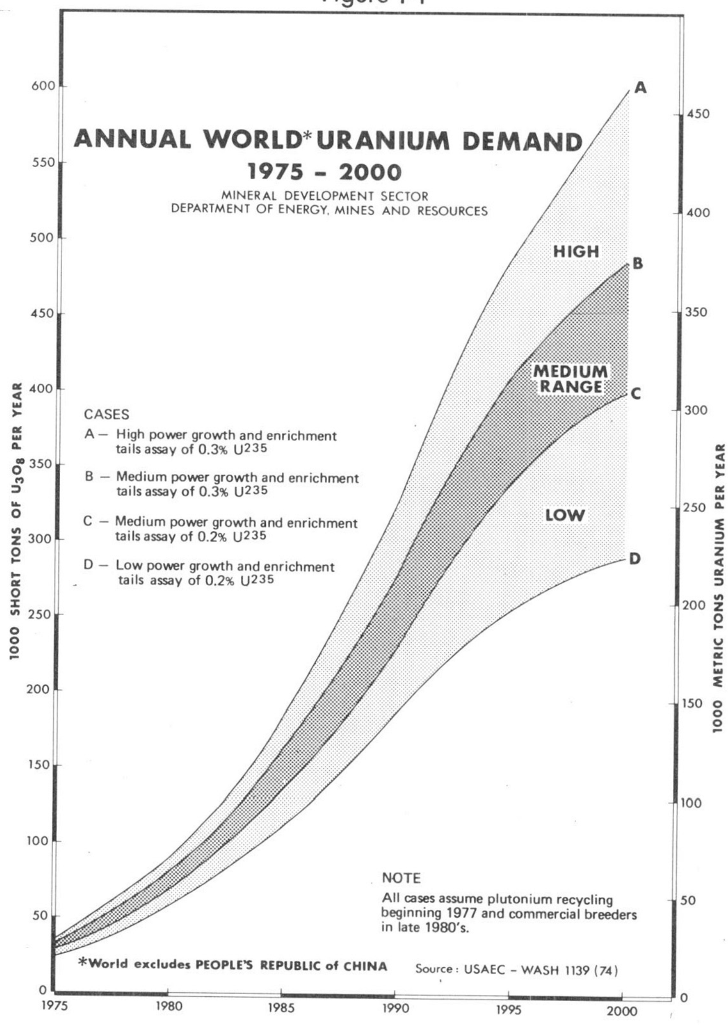


TABLE 1. 1

Forecast of world* nuclear power capacity, 1980 to 2000

(MW x 1000)

Year-End	Low	Medium	High
1980	198	242	279
1985	521	647	695
1990	1 050	1 280	1 475
1995	1 700	2 187	2 560
2000	2 450	3 330	3 950

* World excludes People's Republic of China.
Source: USAEC, Wash. - 1139(74)

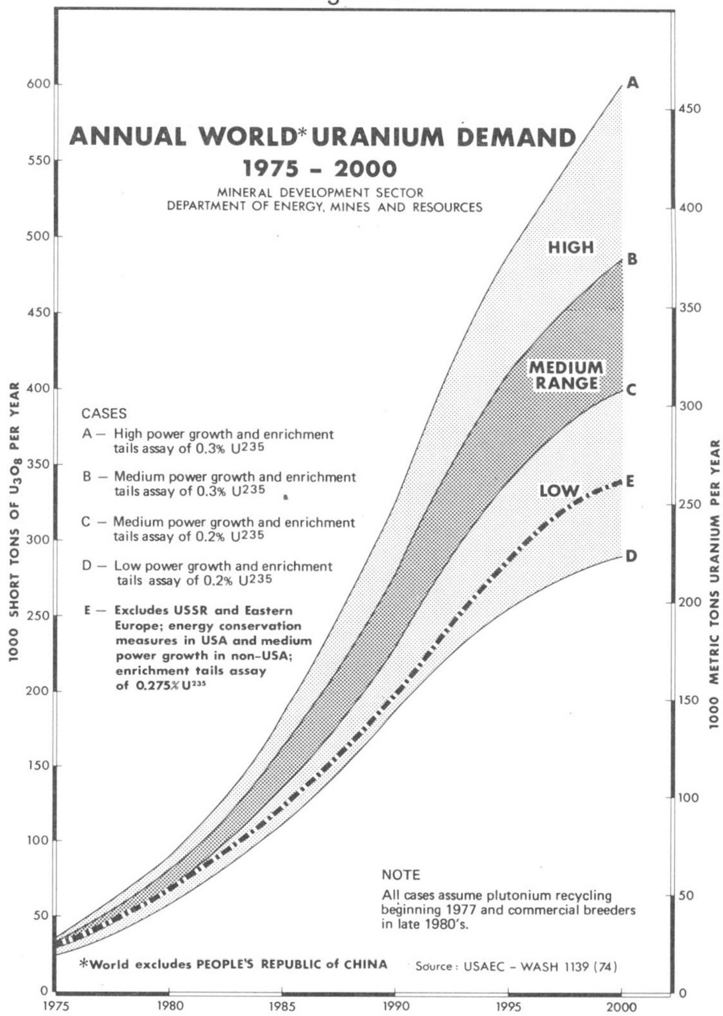
grows from some 30 000 tons of uranium oxide (U_3O_8)[1] a year in 1975, to between 70 000 and 80 000 tons in 1980, and 400 000 to 490 000 tons a year in the year 2000. For the post-1980 period, however, it is more important to look at the range of the projections and the major factors that contribute to this uncertainty range than at the particular forecast numbers themselves. The principal factors include the timing and rate of introduction of commercial breeder reactors, the timing and rate of introduction of plutonium recycling in light-water reactors, the assay of the tails stream from uranium enrichment plants, the particular reactor strategy or reactor-mix chosen for individual countries, and perhaps most important of all, the rate of nuclear power growth.

A number of developments have occurred since these projections were made which, taken individually, could alter this outlook one way or another. Factors that would raise the projections include plans by several countries, particularly France and Japan, to accelerate their nuclear power programs in the wake of the dramatic increase in the cost of fossil fuels; a deteriorating outlook for early solutions to problems besetting the nuclear fuel reprocessing industry and thus a continued postponement of large scale recycling of plutonium; lower than expected fuel-burnup experience with presently operating light water reactors; and the recent decision by the United States' Energy Research and Development Agency (ERDA)[2] to increase its transaction enrichment tails assay from 0. 2 to 0. 275 per cent U^{235} beginning July 1, 1976 and possibly to 0. 30 per cent beginning July 1, 1981. Counteracting

[1] Short tons used throughout; 1 short ton U_3O_8 equals 769. 3 kgm uranium metal.

[2] As of January 21, 1975 the USAEC ceased to exist and two new agencies were created, ERDA and the Nuclear Regulatory Commission (NRC).

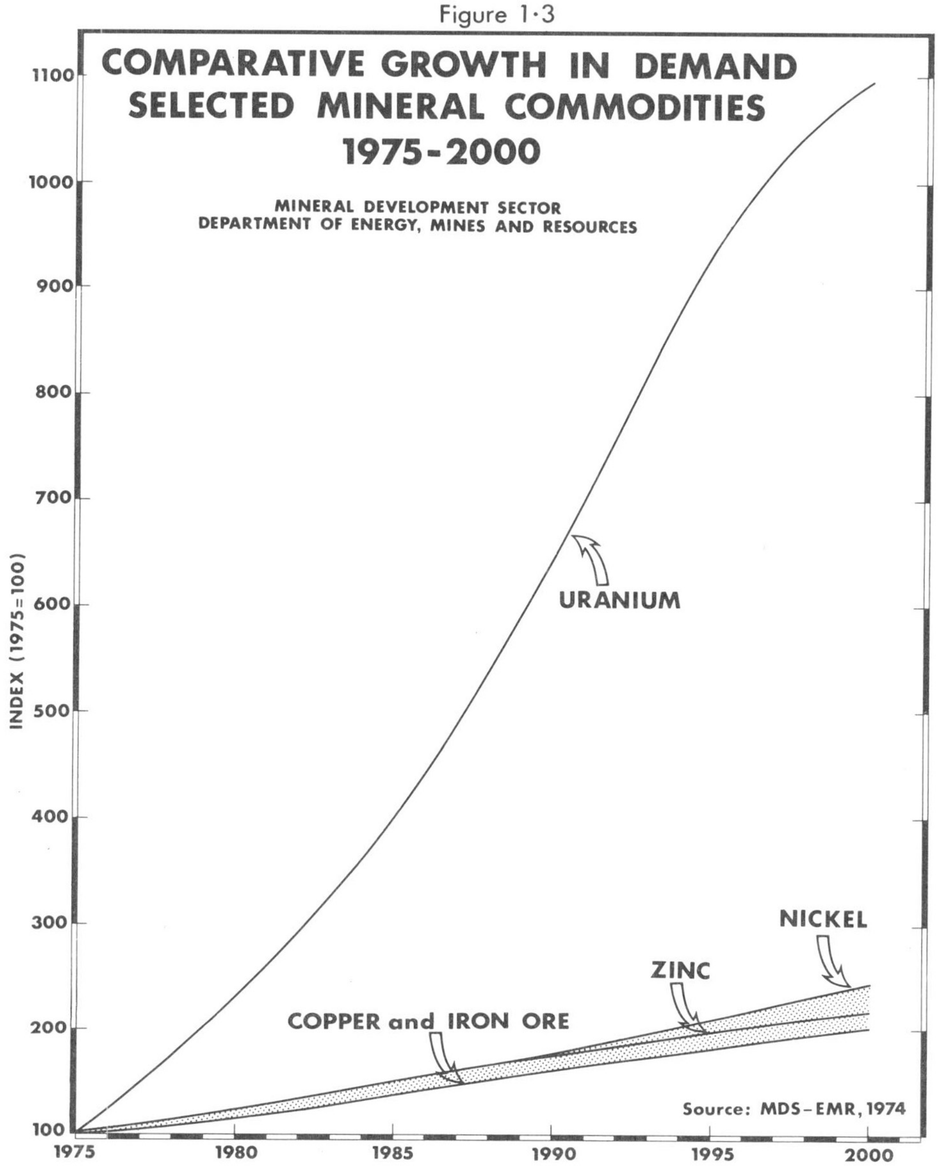
Figure 1·2



factors include the continued gloomy outlook for public understanding of the environmental impact of nuclear power; continued delays in construction due to the regulatory and licensing process but due also to increased incidents of shortages in equipment and supplies; and finally, the cancellation or postponement of nuclear power projects, particularly in the United States, due largely to the inability of utilities to raise the large amounts of required capital. The net effect of all of these factors on the projections shown in Figure 1. 1, however, is likely small.

Before comparing these projections of demand to the supply side of our equation, we must first exclude that part of the world for which we lack supply information. Figure 1. 2 illustrates a case (Case E) which excludes the U. S. S. R. , Eastern Europe and the People's Republic of China. It also assumes an operating enrichment tails assay of 0. 275 per cent U^{235}, a nuclear power growth rate in the United States moderated by energy conservation measures, and a moderate rate of nuclear power growth for the rest of the world. Using these assumptions, annual world requirements are expected to grow from 30 000 tons U_3O_8 in 1975, to 124 000 tons in 1985 and 338 000 tons in the year 2000. This projection is not radically different from that made by the

Figure 1·3



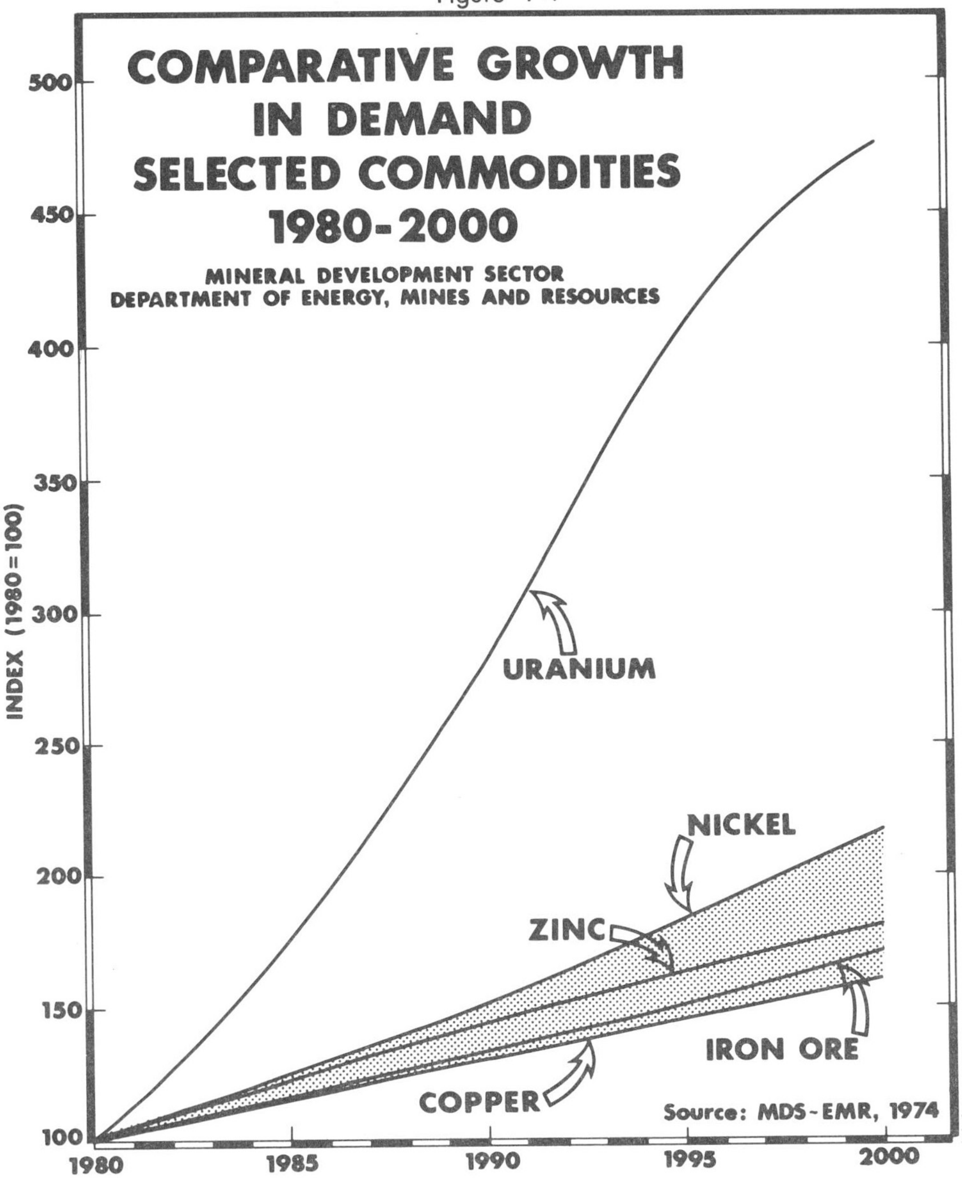
Nuclear Energy Agency of Organization for Economic Co-operation and Development (OECD) and the International Atomic Energy in their study of August 1973 (Lane, *et al.*, 1974; Anonymous, 1973).

It has been stated that the rate of growth in uranium demand is unprecedented at something in the order of 15 to 20 per cent a year over the next ten to fifteen years. Figure 1. 3 illustrates this growth rather dramatically in relation to the expected demand for copper, zinc, nickel and iron ore for the period 1975 to 2000. For uranium, we see a ten-fold increase in annual demand over the next 25 years compared with a mere doubling in demand for the other commodities during the same period. Even when compared with a base year of 1980, the difference in growth rates is startling (Fig. 1. 4).

Exploration and Development Requirements

Given these projections of uranium demand, it is possible to illustrate the requirements for new reserves that must be developed both from known deposits and from deposits yet to be found. Figure 1. 5 illustrates two curves related to Case E as depicted in Figure 1. 2 for the world, excluding the U. S. S. R., Eastern Europe and the People's Republic of China. The lower curve represents the cumulative requirements from 1975 to 1990. However, this curve understates the question of how large our developed reserves need be at any point in time. Because of the time required to replace reserves that are being produced, a viable industry must at all times maintain reserves sufficient to meet an

Figure 1·4



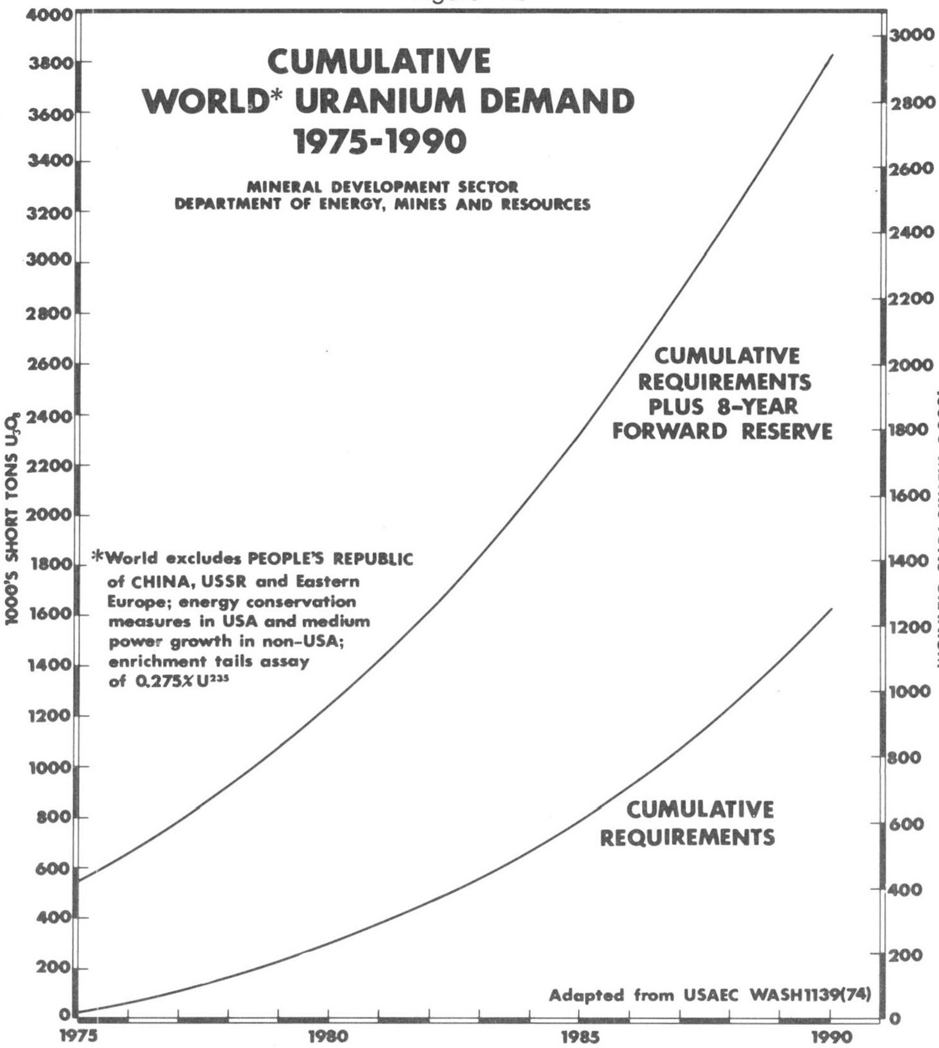
appropriate period of forward requirements. The upper curve is intended to illustrate the reserve position necessary to meet eight years of forward requirements. This curve is derived simply by shifting the cumulative requirements curve eight years backward in time (to the left).

The world's currently delineated low-cost reserves, which we estimate to be in the order of 1. 2 million tons of U_3O_8, are sufficient to meet requirements for the next 14 years. Figure 1. 5, therefore, can be modified to illustrate the desirable growth in the reserve level as shown by curve A-C in Figure 1. 6. (An alternate but less likely growth curve would be A-B-C). From this we can see, in gross cumulative terms, that over the next fifteen year period, we must develop new reserves totalling some 2. 6 million tons of U_3O_8.

Required gross annual additions to reserves can be calculated as illustrated in the upper curve of Figure 1. 7. However, again we must adjust for our present surplus reserve position and construct a modified curve (lower) beginning at a point equivalent to recent average annual additions to reserves, which we estimate to be in the order of 90 000 tons of U_3O_8 a year. The rate of growth of reserve additions would likely be moderate at first then accelerate in the early 1980's. Our conclusion is that, in the world context, annual gross additions to reserves must triple to something like 270 000 tons of U_3O_8 a year by 1990. If all additions to reserves were to come from new discoveries alone*, it has been estimated that annual world

*Reserve additions can also come from presently known sub-economic resources, as a result of changes (largely through research and development) that lower exploitation costs relative to uranium prices.

Figure 1·5



exploration expenditures would have to grow to between $500 and $600 million by 1990 (Williams, 1973).

These kinds of projections are useful for illustrating qualitatively the supply-demand situation on a world basis or for countries like the United States that have a very large production base. For a more comprehensive assessment it is necessary to examine the supply situation in much more detail, indeed on a mine by mine basis. Figure 1. 8* illustrates, for Canada, the future level of production that must be achieved, if Canada is to continue to supply roughly 20 per cent of world requirements. The relative proportion of domestic requirements is shown by the lower curve.

A detailed examination of Canada's known uranium reserves and resources (Fig. 1. 9*) shows that existing mines and known deposits whose future development is almost certain, can supply an appreciable portion of Canada's total requirements (export and domestic). Production levels from these sources will peak in the early 1980's at about 15 000 tons of U_3O_8 a year, then decrease as some deposits are depleted and as average grades of others decline. The effect of the very large deposits at Elliot Lake is very noticeable, in that significant production levels will be maintained in this area well into the next century. Clearly, additional production will be required from 'new sources', and the reserves to support this new production must be discovered with sufficient lead-time to allow for development of the deposits and construction of the plants.

When considering these new sources, it is possible to improve on a simple eight-year forward reserve formula by considering the types of deposits, in terms of size and grade, that may be discovered during the period. An internal study which is underway in the Mineral Development Sector, Department of Energy, Mines and Resources (EMR), is examining this question in detail for a number of commodities, working out illustrative examples based on models taken from past production history. A typical relationship between metal production capacity and reserves is shown in Table 1. 2 for three types of copper mines. The table

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* Figures 1. 8 and 1. 9 are based on 1972 data. New data would not radically change the shape of the curves.

Figure 1·6

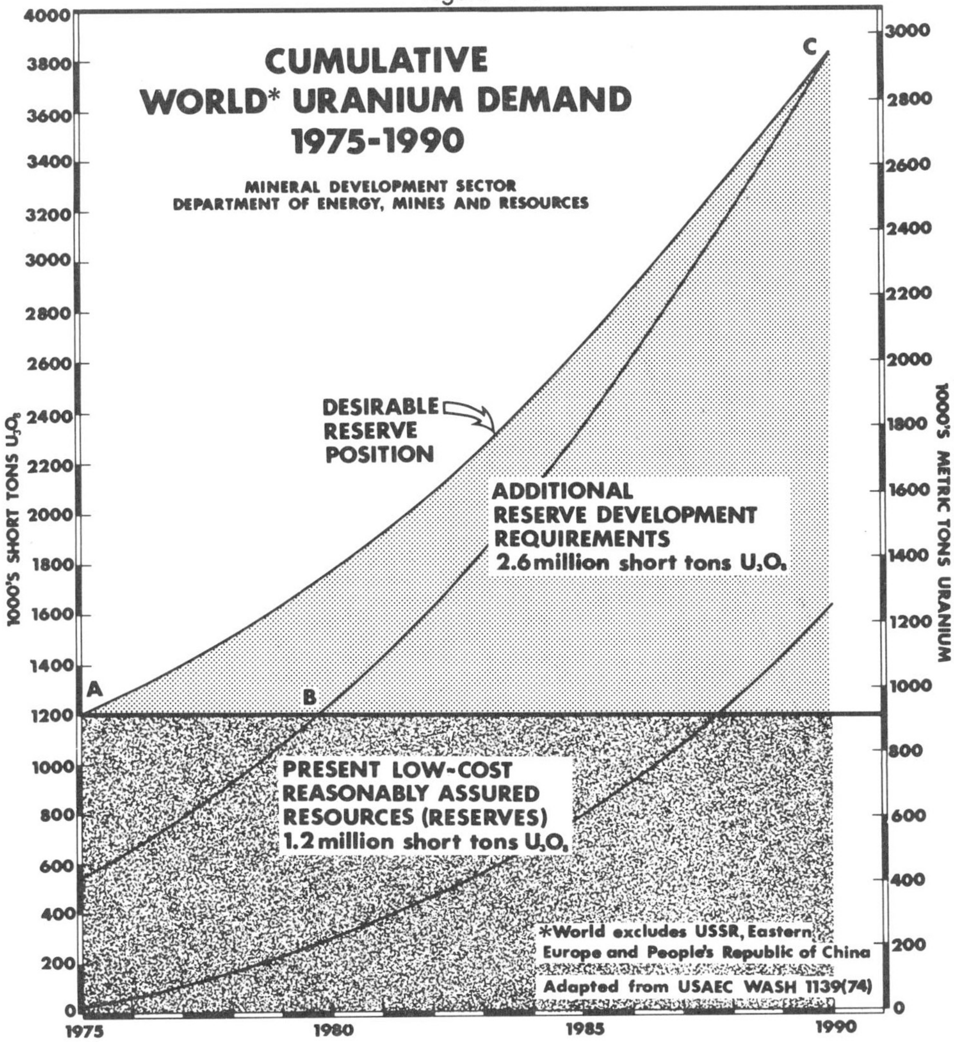


Table 1. 2

Relationship between metal production capacity
and required reserves (contained metal)
in three types of copper mines

Number and Size of Mines	Ore Reserves Per Mine: During Early-Life[1] (Tons x 10^6)	Ore Reserves Per Mine: "Life-Time"[2] (Tons x 10^6)	Ore Grade (% Cu)	Total Contained Metal In Reserves All Mines (Tons Cu)	Daily Mine Production Per Mine (Tons Ore)	Annual Total Metal Production[3] All Mines (Tons Cu)
3 Large	200	250	0. 5	3 750 000	30 000	135 000
6 Medium	40	60	1. 5	5 400 000	5 000	135 000
10 Small	5	10	3. 0	3 000 000	1 500	135 000

[1] Typical "Proven reserves" during early life of mine.

[2] Total reserves cumulated over the life of the mine.

[3] Assume 100 per cent recovery.

Figure 1·7

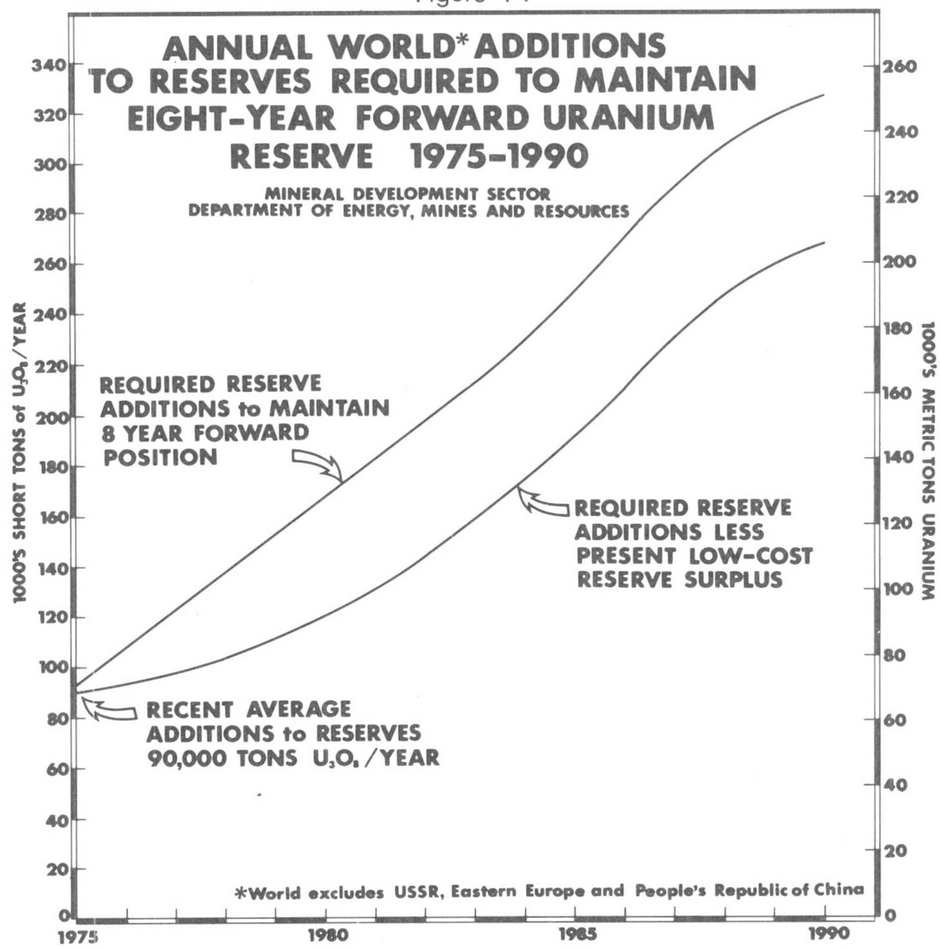


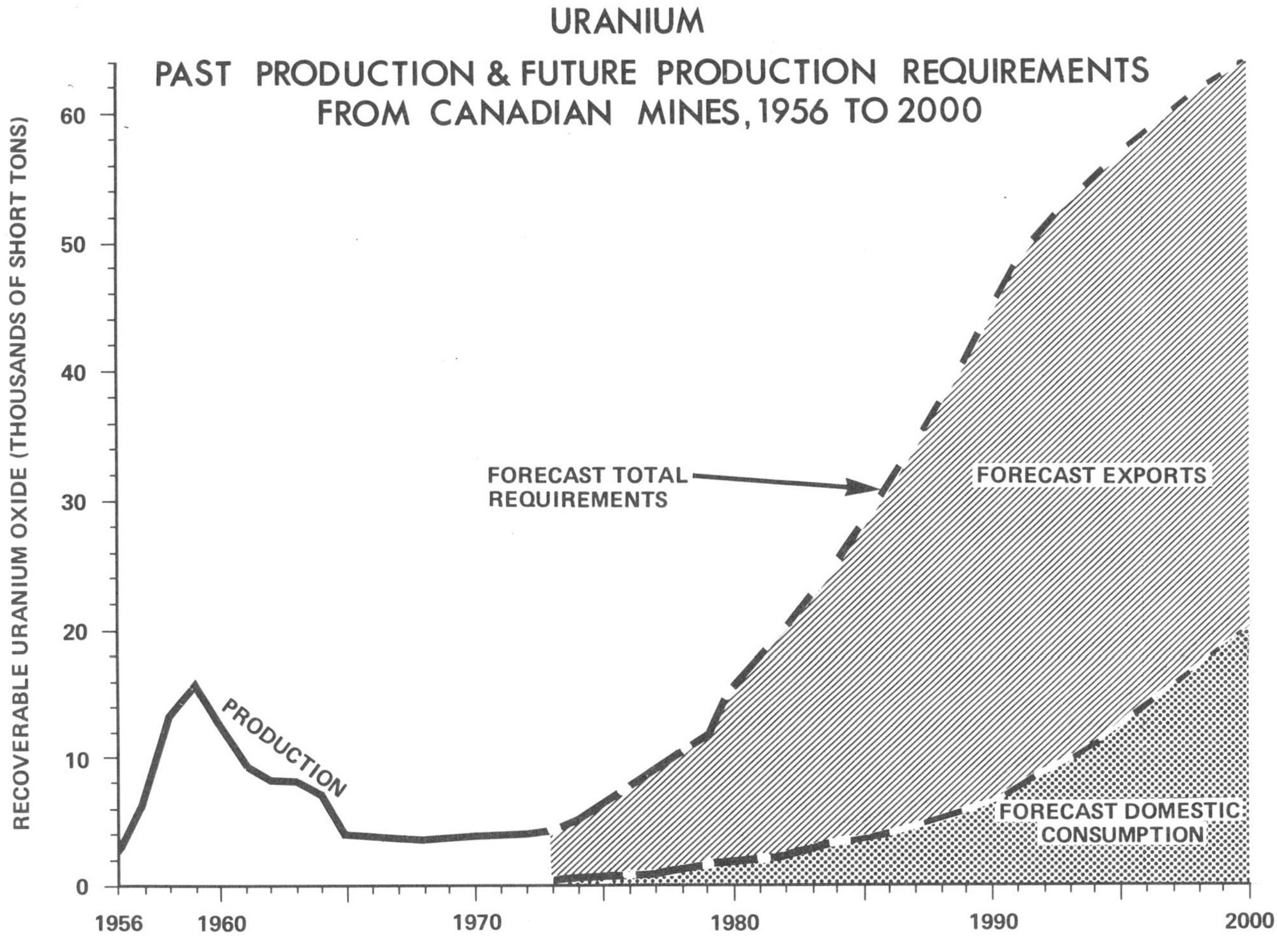
Table 1. 3

Future discovery requirements for uranium in Canada, 1976 to 1995

Discovery Period	If all new source requirements are met from A or B or C					
	A		B		C	
	Small-Sized Mines of Medium Grade		Medium-Sized Mines of Medium Grade		Medium-Sized Mines of Low Grade	
	"Life-Time" Reserves Tons U_3O_8 X 1000	Number of Mines	"Life-Time" Reserves Tons U_3O_8 X 1000	Number of Mines	"Life-Time" Reserves Tons U_3O_8 X 1000	Number of Mines
1976-80	80	8	280	5	100	8
1981-85	180	19	660	12	230	18
1986-90	280	30	770	14	280	22
1991-95	280	30	390	7	240	19
1976-95	820	87	2 100	38	850	67

"Life-Time" reserves of a mine are meant to express the total tonnage of contained U_3O_8 likely to be produced during the life of that mine.

Figure 1·8



shows that, in terms of providing a certain amount of annual production, the largest quantity of total metal reserves is required if production comes from medium-sized mines. It follows that, if we were to discover and develop a large number of small-sized, medium- to high-grade deposits, on an appropriate time scale, we could meet our future requirements with a minimum of forward reserves.

The study by the Department of Energy, Mines and Resources assessed discovery requirements for several commodities for the period 1976 to 1995, allowing for development lead-time to meet the production required from new sources to the year 2000. The assumption was made that all new sources were yet to be discovered. In the case of uranium, three combinations of size and grade were considered; the results are summarized in Table 1. 3. Again, it is more important to observe the range and order of magnitude of these projections than the absolute values. As with all studies there were a number of assumptions that had to be made which can undoubtedly be debated. Certainly in the case of uranium, there is some risk in the use of the absolute values since the production history is short relative to other commodities and, consequently, the number of mines upon which the models were based is statistically small. The study does illustrate, however, that the total tons of U_3O_8 that need to be discovered and developed between now and the end of the century will vary widely depending on the order in which deposits of different sizes and grades will come on stream.

Future Exploration Strategy

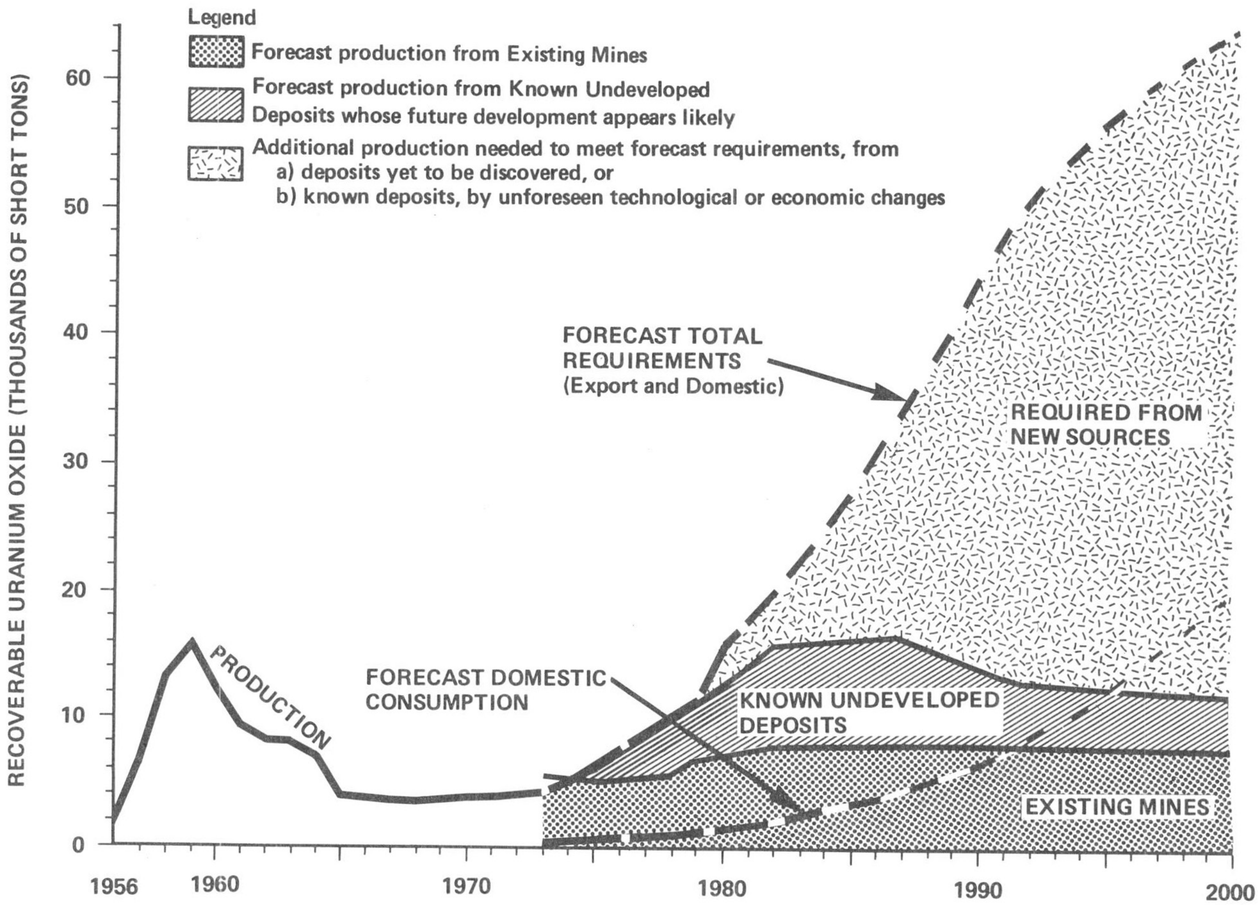
Having examined the projected demand for uranium from several points of view, it is clearly evident that the challenge is a great one, and that the time available to accomplish the task is all too short. If uranium is to be discovered and developed for production at a rate sufficient to meet demand, there must be a rapid and accelerating expansion of exploration effort. However, this alone will not be enough! Our exploration philosophy must be re-examined and perhaps modified to make more effective use of the exploration technology available to us. Even more important, new methods of financing these efforts must be developed to meet the needs of all participants, given the political realities of today. An examination of some of these factors may be useful.

In the past, exploration objectives have been biased to some extent by the types of deposits familiar to those conducting the programs and by the type of deposit that has proved to be the most lucrative prize. Geologists around the world have tended to specialize in the types of deposits that have provided production in their

Figure 1·9

URANIUM

FORECAST SOURCES OF CANADIAN PRODUCTION TO THE YEAR 2000 TO MEET FORECAST REQUIREMENTS



respective countries. United States geologists, for example, are acknowledged experts on sandstone-type deposits, Canadians generally know a lot about conglomeratic, vein-type and pegmatitic deposits, and French geologists have led the way with recent interpretations of the genesis of vein and replacement-type deposits. The bulk of exploration programs in these countries has, to date, been concentrated in areas favourable for the occurrence of the same types of deposits. In this respect, geologists in countries not blessed with large resources of uranium tend to be better prepared for the challenge of the 1980's, in that they have made it their business to familiarize themselves with the entire range of geological types of uranium deposits (Gableman, 1974b).

It is becoming more and more evident that we cannot expect to discover much larger deposits of the types now being exploited. Either new types of deposits must be found and developed or we must find much larger numbers of the same size deposits we are now exploiting, which may be a difficult task. There is a growing amount of evidence in the United States, for example, that the distribution of sandstone-type deposits may be limited and that this type of deposit may not be able to supply that country with its future needs (Nininger, 1974). Our philosophy should be to look for all types of deposits, including those which may be entirely new and which have yet to be identified.

Exploration to date has generally been directed toward deposits with average grades greater than 0.1 per cent U_3O_8. It is this quality of deposit from which the bulk of world production has come and with which we are most familiar in terms of economic geology and known reserves and resources. We also know quite a lot about resources of uranium available at very high costs, from such sources as the Chattanooga shales, from above average-grade granites such as the Conway granites, and from certain phosphate rock formations. Grades from these sources range from 0.01 to 0.001 per cent U_3O_8 and costs of recovery probably lie in the range of \$50 a pound to more than \$100 a pound U_3O_8. These sources have been investigated partly for

academic reasons and partly because they represent fall-back alternatives, should exploration for conventional sources be unsuccessful (Nininger, 1974; Bieniewski *et al.*, 1971). There is, however, a great gap in knowledge about sources of uranium between these two extremes, mainly because almost all exploration effort has been directed toward low-cost uranium.

There is every expectation to believe that once exploratory efforts are redirected toward sources of uranium with grades lower than 0.1 per cent U_3O_8 substantial resources will be identified. With increased prices of uranium and assured markets, some deposits containing as little as 0.03 per cent U_3O_8 will likely soon be economic; the Rossing deposit in South-West Africa (Namibia) is the first lower grade deposit to be developed (Armstrong, 1974). The potential for discovery of uranium deposits with grades in the range of 0.1 to 0.01 per cent U_3O_8 should be sufficient in order that dependence upon uranium from sources like granites and shales would not be necessary, at least not during this century.

As exploration expands in search of new types and lower grade deposits in areas away from traditional geological environments, it may be useful to re-examine our guiding geological concepts. The objective of many recent exploration programs has been to search for extensions of known geological districts, often using statistical or engineering approaches. Where interpretative geology has been used it is based on concepts modelled on known deposits. While this type of approach may be adequate for identifying new deposits in familiar environments, it may be totally inadequate for selecting new areas. It may be time to take a less conservative approach. Enough examples of different uranium occurrences have been found in the world so that complete ranges of genetic processes and controlling environments have been interpreted or conceived (Gableman, 1974a). It should no longer be acceptable to dismiss categorically particular environments as areas having little potential for uranium.

Exploration for uranium will become increasingly challenging, since the bulk of surface occurrences in readily accessible areas has likely already been discovered. Consequently, it will become more important to make the most effective use of all of the exploration technology available to us. There have been significant advances in recent years; for example, in gamma-ray spectrometry, radon emanometry and geochemical prospecting techniques. In addition, recent Canadian uranium exploration programs have successfully employed magnetic, resistivity, and gravimetric techniques. The search for concealed deposits will necessitate more 'wildcat' drilling which will contribute to the wider use in Canada of percussion drilling techniques, combined with radiometric logging. Even with all of these advanced techniques the search will be most difficult and there will be a continued need for improvements in exploration technology. Above all, programs will have to be more detailed and more systematic than in the past.

Financing Alternatives

One of the biggest challenges of the 1980's will be the financing of the required exploration and development effort. Two related factors which have contributed to the disinterest in uranium exploration during recent years have been low prices and oversupply. This situation has changed recently, however, with prices returning to more equitable levels and a sellers' market emerging over the past year. As to the future, a new mechanism is evolving based on world market prices at time of delivery, with a floor price to provide down-side protection for the producer (Albino, 1974). In addition, recent contracts contain formulae for sharing the risk of currency fluctuations, and many have also provided for substantial down-payments to finance producers' expansions.

Another factor – the growing concern by various governments about the ownership of natural resources in general and of uranium resources in particular – has contributed to difficulties in financing exploration and development projects using foreign capital. In the face of these political realities however, there is growing evidence, although difficult to document, that new methods of foreign, non-equity financing are beginning to evolve. Various consumer entities in countries not blessed with domestic resources of uranium have been involved for sometime in uranium exploration and development ventures abroad. With the shift to a sellers' market during the past year, there also seems to be a shift in priority on the part of some consumer participants in these ventures, from equity participation, to any form of arrangement which will guarantee them a share of production for their nuclear power needs.

A similar kind of evolution is evident on a national scale in the United States, where a number of utilities have taken steps to obtain supplies of uranium by participating directly in uranium exploration programs. The principal example is the Tennessee Valley Authority (TVA) which has agreements with four United States uranium companies involving exploration rights and shares of production. In one case, the Tennessee Valley Authority must pay all exploration costs and, in addition, must pay all costs plus a royalty on future production equal to 50 per cent of the difference between costs and the market price for uranium at the time. A more recent example involves Texas Utilities Fuel Co. (TUFCO) which can participate for up to ten years in an exploration program with Ranchers Exploration and Development Corp., by providing over 85 per cent of the financing but gaining only 50 per cent of the equity.

The point to be made here is that a participant's share of production need not be directly related to his share of the equity. This type of consideration is not peculiar to uranium. An example in the case of oil, involves the agreement between the Saudi Arabian government and Arabian American Oil Co. (ARAMCO). ARAMCO's equity is limited to 40 per cent but its share of production is 76 per cent. In addition, ARAMCO is free to buy some of the remaining 24 per cent of production (Oil and Gas Journal, July 17, 1974). A

Canadian example in the case of coal is Kaiser Resources Ltd. In this case, Mitsubishi Corp. and its Japanese customers have an equity of some 30 per cent, but acquire essentially 100 per cent of the production. An example that may be more familiar to you is that of the Strathcona Sound lead-zinc project on Baffin Island, which is being developed by Mineral Resources International Limited. In this case, the foreign participants, Metallgesellschaft A. G. of West Germany and Billiton B. V. of Holland, have a combined equity position of 23 per cent but are guaranteed at least 80 per cent of the concentrates.

There are other ways of controlling equity limits, particularly at the development stage, including such things as production royalties and management agreements. The most obvious method, is the use of debt financing. It is pertinent to recall that the first large-scale application of debt financing in Canada's mining industry was for the development of the Elliot Lake deposits in the 1950's. Debt financing has become more common over the past decade. Recent Canadian examples include Gibraltar Mines Ltd. and Mattabi Mines Limited, which negotiated term loans with chartered Canadian banks in the amounts of $63. 9 million and $45 million respectively, representing close to their total cost of development. Significant portions of debt capital can also be made available under the terms of sales contracts. This was the case, for example, with Lornex Mining Corporation Ltd. which borrowed $28. 6 million from its Japanese customer-consortium and with Sherritt Gordon Mines, Limited, which borrowed $15 million (US) from the Mitsubishi group for the development of its Ruttan mine (Worth, 1974; Fielder, 1974). It is this latter type of debt capital which will likely become more commonplace for the development of future uranium projects.

Conclusion

It is worth noting that a major turning point in the history of Canada's uranium industry has been reached and that the outlook for uranium is enviable with respect to the future of other commodities. Demand is growing at an unprecedented rate, a sellers' market will likely prevail for an extended period of time, present prices are about $15. 00 a pound U_3O_8 and an equitable future pricing mechanism is being developed. The history of uranium exploration in Canada has been relatively short, and the geological potential for future discoveries is considered excellent. Hopefully, there will be a continued evolution in methods of financing exploration and development efforts, in ways that will satisfy the growing aspirations of governments and, at the same time, provide the needed financial incentive to industry, as well as an assurance of supply to any participating consumers. Given these prerequisites, together with an exploration philosophy designed for the 1980's, there is every reason to expect that uranium may once again rank as Canada's principal mineral product.

These views may appear to be optimistic or even a little bit unrealistic but there can be no denying the fact that the challenges of the 1980's will be difficult and that there are many issues yet to be resolved; however, a pessimistic and conservative response to these challenges will not likely contribute to successful solutions.

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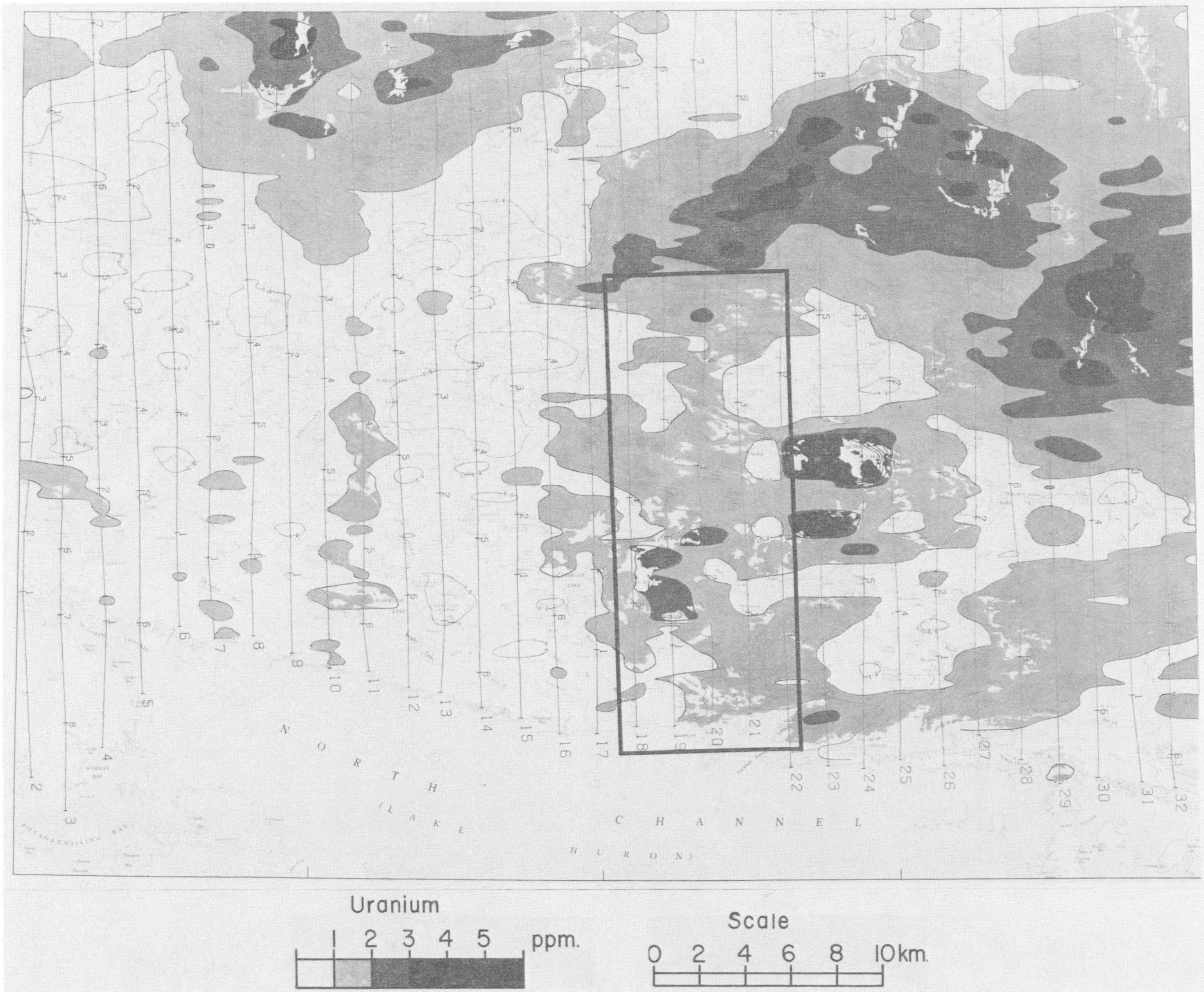

Figure 5.2. Uranium distribution, Blind River sheet, Ontario.

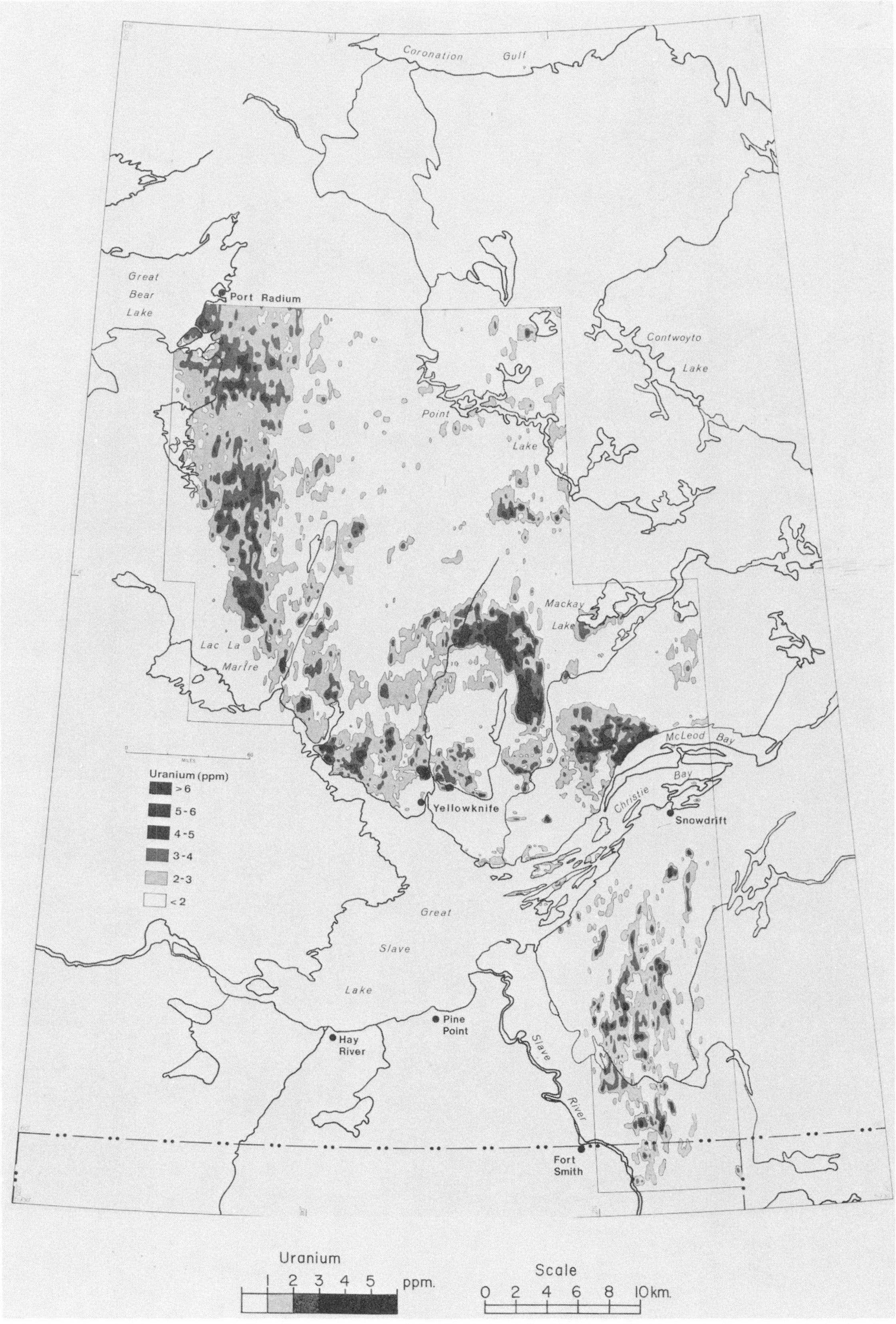

Figure 5. 12. Uranium distribution, northwest margin of Canadian Shield.